Outdoor Science Activity: "Orienteering" Walk Through the Solar System

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The importance of outdoor learning is recognized for several reasons, as described, for example, in Refs. 1 and 2. It has always been a challenge and an opportunity, and in an era when viruses roam indoors in dangerous quantities, it is even more important to use the outdoors whenever possible to learn curriculum content.[3] The activity described in this article is part of the science curriculum (physics and astronomy), but can be combined with several other subjects as part of an entire outdoor activity day. It also requires additional and unusual teacher involvement, as described below.

The main content of the learning unit presented in this article is the solar system. One of the basic goals of teaching about the solar system is to allow students to develop an idea of the dimensions and scales: the distance between the Sun and the planets and the size of the Sun and the planets. The teacher can help students achieve this goal by using physical models that show the solar system at a reduced scale.[4,5] However, it is rare to find a model that uses the same scale for both dimensions, the distance of the planet from the Sun and the diameter of the planet.[6] The two dimensions themselves are on such different length scales that it is difficult to build such a model that will fit in a typical classroom: If the Sun is in one corner of the room and Mars is in the opposite corner (for a model of the inner planets of the solar system), say 10 m apart, the diameters of the spheres representing the Sun, Mercury, Venus, Earth, and Mars would be 6.1 cm, 0.21 mm, 0.53 mm, 0.56 mm, and 0.30 mm, respectively. If you want to place not only the inner planets but all eight planets in one classroom, divide the sphere diameters by 20.

Our idea is to use a scale that is easy to achieve outdoors: we chose to place Earth 100 m from the Sun ($1\ \mathrm{AU} = 149.6 \times 10^9\ \mathrm{m} \approx 150 \times 10^9\ \mathrm{m}$ in nature corresponds to 100 m in our model). At this scale, Mercury, Venus, and Mars are about 39 m, 72 m, and 152 m from the Sun, respectively. The spheres representing the Sun and inner planets would have diameters of 93 cm (a large Pilates ball representing the Sun), 3.3 mm (Mercury, a small dry green pepper seed), 8.1 mm (Venus, a chickpea seed), 8.5 mm (Earth, another chickpea seed), and 4.5 mm (Mars, a small juniper berry or common black pepper seed), as shown in Fig. 1. If you choose to include Jupiter, its model should be a 10-cm-diameter orange about 500 m from the model of the Sun.

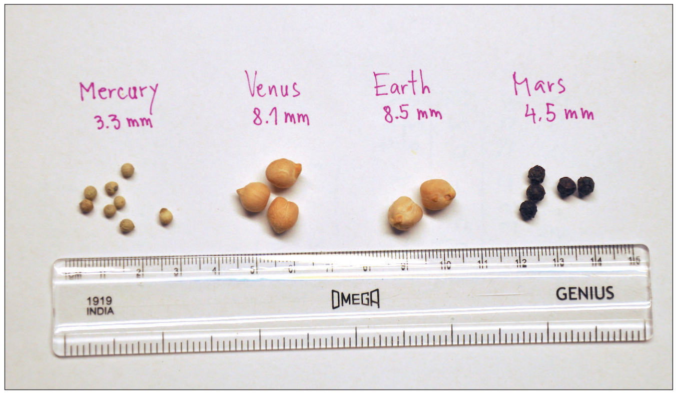

Fig. 1. Seeds as models for planets in the solar system with a scale where 1 AU is represented with a distance of 100 m.

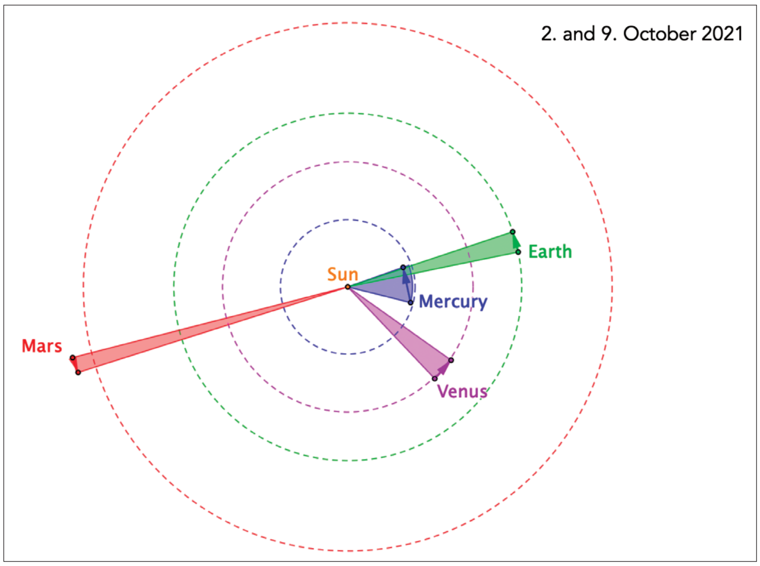

Fig. 2. Position of the inner planets in the ecliptic plane on two different days, one week apart, as seen from the north side of the ecliptic plane. All planets orbit the Sun in the same sense and approximately in the same plane. The dashed circles have radii corresponding to the average distance of the planets from the Sun. (The planetary orbits are elliptical, and the distance of each planet from the Sun during its orbit around the Sun changes a little and most likely deviates a little from the average distance at most times.)

Locations of the planets in the neighborhood

Now for the locations: We do not place the planets in a row, but arrange them around the Sun as they are distributed on a given day, thus pursuing another important goal. The planets are not stationary, but always in motion, orbiting the Sun in different orbits, with different speeds and orbital periods. These features of the solar system can be much better illustrated with a model that also takes into account the motion of the planets. The arrangement of the planets around the Sun is not the same on different days. If the main activity is done today, students can spend some time after a week reviewing the displacement of the planets, provided the teacher has shifted the planet models appropriately to their new current positions. Figure 2 shows the positions of the inner planets of the solar system on October 2, 2021, and one week later, on

Planet Summary

Year 2021 Month October Day 2 Time 21:40:00

	Mercury	Venus	Mars
Right ascension	13h 20m 42.3s	15h 26m 48.6s	12h 42m 48.6s
Declination	-12° 13' 54"	-21° 10' 47"	-3° 51' 7"
Range (AU)	0.684	0.873	2.633

(a)

	Sun	Mercury	Venus	Mars
RA - h	12	13	15	12
RA - min	35	20	26	42
RA - sec	20	42	49	49
DEC - deg	-3	-12	-21	-3
DEC - min	48	13	10	51
DEC - sec	28	54	47	7
range - AU	1	0.684	0.873	2.633

(b)

Fig. 3. (a) Screenshot of ephemeris data from the Heavens Above website[8] and (b) the same data in the GeoGebra application.[9]

October 9, 2021. In the model, Mercury has moved about 19 m, Venus about 14 m, Earth about 12 m, and Mars about 10 m.

There are many websites with realistic simulations of the motion of the planets.[7,8] One can use the sketch from the simulation, but we find it easier (for use with a map explained below) to use our own GeoGebra app (GG app),[9] which fixes the planets to their current positions in an ecliptic plane using the ephemeris data we provide (the ecliptic plane is the plane of Earth's orbit around the Sun). There are also many websites with interactive access to the ephemeris data,[10,11] and the GG app can be used to easily design an arrangement of the planets to suit one's purposes and environment.

One needs to enter three parameters for the Sun and each planet into the GG app: the current (or on the selected day) right ascension (RA; given in hours, minutes, and seconds), declination (DEC; given in degrees, minutes, and seconds), and range R (distance from Earth, given in AU) [they are shown in Fig. 3(a), a screen capture from the Heavens Above website[8]]. Right ascension and declination measure the position of the planets in the equatorial coordinate system (this is the same system we use to describe the geographical position on Earth), and range measures the current distance of the planet from Earth. The application [Fig. 3(b)] calculates the ecliptic coordinates of the planets and displays their positions in the ecliptic plane, as shown in Fig. 2.

The next step is to underlay the model of the inner planets with a map of the neighborhood that you use for the orienteering walk. One way to create a map is to use the Google My Maps application with the "Draw Lines of Known Length" tool or the "Measure" tool to adjust the scale of the map to the scale of the solar system you are using in the model. Figure 4 shows the map of the area surrounding our school with a line marking a distance of 300 m.

The procedure for creating a scaled neighborhood map superimposed on the current map of the inner planets on the ecliptic plane is as follows: Display the desired neighborhood map at an appropriate scale, draw a line of known length, export the map as an image, import this image of the map into the GeoGebra application, and use the tools created in the GG app to match the scales of the map and the planet model. The GG app contains a detailed description of how to achieve the matching. A superposition of the map and the planet constellation is shown in Fig. 5(a).

After the scale adjustment, determine the position of the Sun in the neighborhood: where the orienteering can begin. You can place the model of the Sun in front of the entrance door of the school or in any other prominent place you think suitable by moving the point that marks the Sun's position.

Fig. 4. A map of the area where the orienteering will take place, with a 300-m line to match the scale of the map and the model of the solar system.

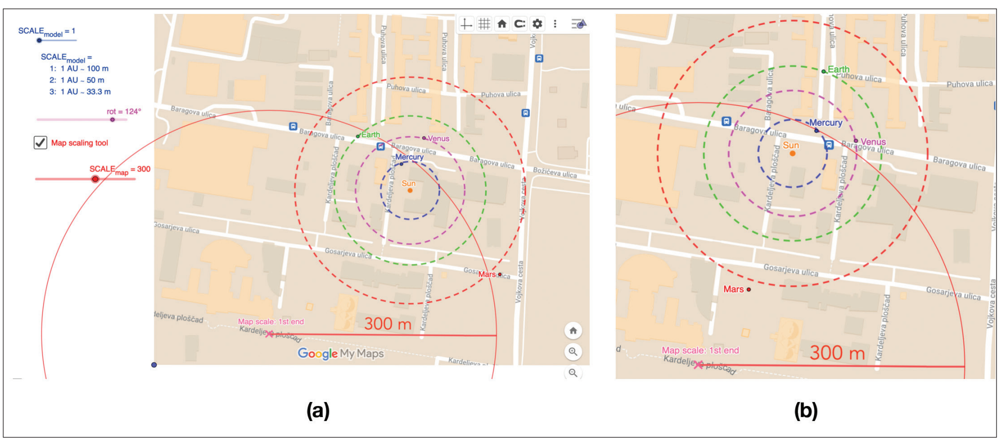

Fig. 5. (a) Superposition of the neighborhood map with the map of the current locations of the planets. (b) Another possible arrangement of the planets in the same area.

Fig. 6. (a) Planetary models in glass jars. (b) Glass jar with Venus model in place.

The planets will move accordingly. You can use a slider to rotate the planetary constellation model to achieve a suitable distribution of planets around your school and avoid having a planet on the roof of the building or in the middle of the busy street. Another possible arrangement of the planet models is shown in Fig. 5(b).

Each tiny planetary model is placed in its own glass jar, as shown in Fig. 6(a), so that it is not lost in the grass and can be observed while searching for the sites. The jars will be taken to the sites in advance and placed there so that they can be found later by students participating in an astro-orienteering walk [see Fig. 6(b)]. Additional information such as diameter, mass, number of moons, etc., of the planets can be indicated on the labels.

The activity

There are a few ways in which the participants in the activity look for the planets. Obviously, they cannot just walk around hoping to find a planet model that is somewhere in a circle with a radius of 150 m around the model of the Sun (when using the scale of 1 AU = 100 m and including only the inner planets). They should be given concrete clues to help them find the planets. Provide rulers and protractors in addition to the map of the neighborhood. The clues can be differentiated depending on the skill level of the participants. The following are some possible clues. The first two (maybe three, depending on how much time is available for the activity) should be distributed to everyone. Instead of providing the map, participants can also use map apps on their smartphones if you allow use of them. Our experience with giving clues 1–4 (without using smartphones) is that it takes an average group of high school students about 1.5 hours to locate all

Fig. 7. High school students engaged in the activity at astronomy summer school.

the inner planets, if we use the scale where 1 AU corresponds to 100 m.

1. Clearly show the model of the Sun: this is the starting point.
2. A sheet of paper with a schematic representation of the current position of the planets in the ecliptic—at a specific or unknown scale [if unknown, data on the current distances of the planets should be available; from the Sun, or alternatively from Earth, as in Fig. 3(a), so that participants can use their knowledge of geometry to determine the scale].
3. Provide a second sheet of paper with the neighborhood map at an appropriate scale so that all locations of the planetary models are visible (but not marked) on the map.
4. Point the direction to the nearest (or another) planetary model, Mercury.
5. Indicate the distance of the Mercury model from the

Sun model, or provide a suitable tape measure or measuring wheel, or even an ordinary bicycle, to measure this distance.

To facilitate the activity, the teacher may consider forming teams. Working in teams is beneficial for team members as they learn to share their own ideas and consider the ideas of other members on how to proceed and evaluate different proposals. Successfully solving the problem requires skills in a variety of areas, and those who have good spatial awareness can be invaluable to the task. Working in teams clearly helps to solve this task more efficiently and quickly. In our case, the teams consisting of three randomly selected members were the most equal and therefore the most effective, as everyone felt equal and could contribute their different skills. We are pretty sure that the teachers who want to do this activity will have some experience in team formation and will decide according to their experience.

Conclusions

We have presented an outdoor educational activity that helps participants develop a sense of sizes, distances, and the vast empty space in the solar system. With selected information to begin with, the challenge to determine the current positions of the planets in the neighborhood is just right to encourage engagement from all participants.

We tried the activity in different groups: a random audience at public astronomy days in the city, elementary school students in science camp, prospective teachers (students) as part of the exercises, high school students attending the astronomy summer school (Fig. 7), and a mixed group of our own students and Erasmus+ students (Erasmus+ is the European Union's program to support education, training, youth, and sport in Europe), and it was a success for all, in our view. In addition to the content objectives (better understanding of the relative sizes and distances in the solar system and the vast emptiness of space, the relative positions of the planets, and how these positions change over time), some other objectives were also achieved, such as improving students' social skills by working in teams. The activity can be further developed to include other content: for example, this could be natural and artificial satellites and their current position in the solar system, or introducing new concepts such as elongation, conjunction, and opposition of the planets, or even using a larger scale and taking an orienteering tour of the galaxy!

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